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Crocker Pond, Falmouth

Appendix X

Crocker Pond, Falmouth Potential Soil Attenuation of Phosphorus Migration from Infiltrating Treated Wastewater at Site 7

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1 Project Objective

This technical memorandum summarizes the potential environmental impact of expanding wastewater infiltration beds at the Falmouth Wastewater Treatment Facility (WWTF). The issue of primary interest is migration of wastewater phosphorus through the soil matrix and impact on downgradient freshwater resources, including Crocker Pond.

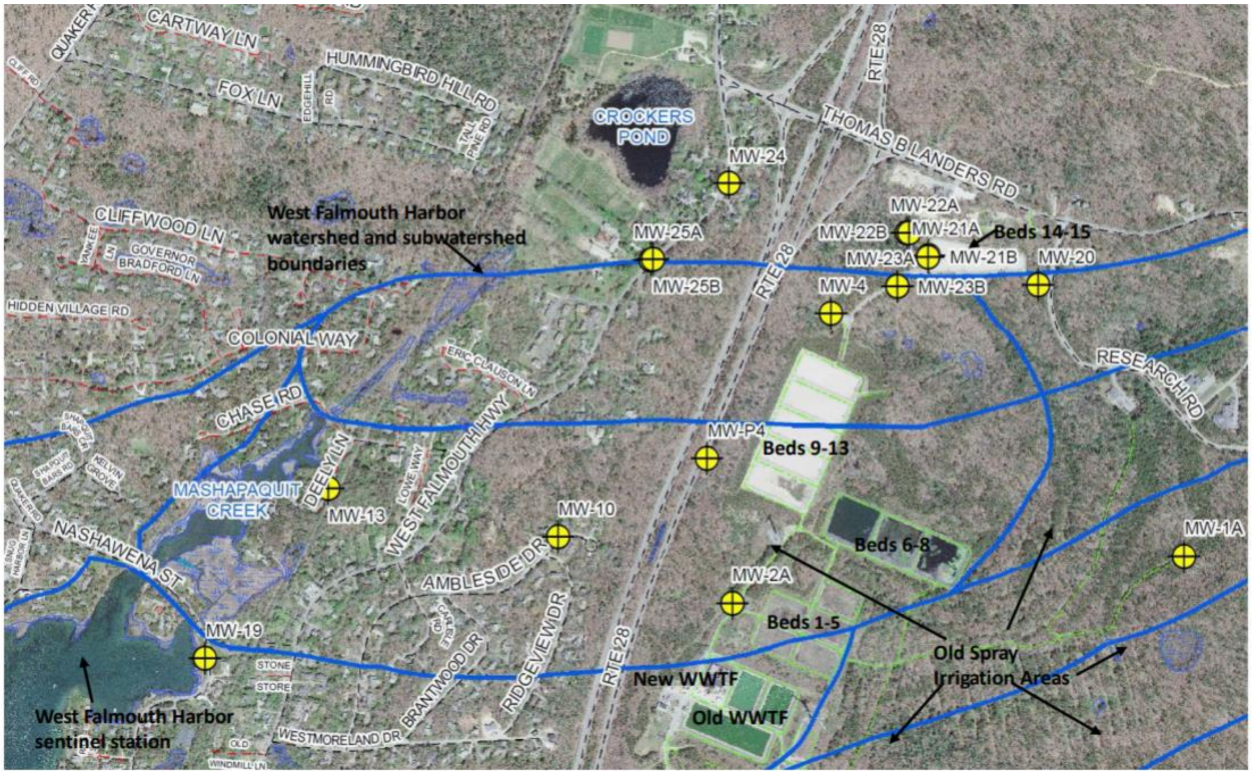
Our analysis builds on a report we completed in 2013 on behalf of GHD and their ongoing wastewater management planning support to the Town of Falmouth (EcoLogic 2013). This memorandum reviews the estimated phosphorus adsorption capacity downgradient of wastewater infiltration at Site 7 and evaluates recent water quality monitoring data in downgradient monitoring wells and Crocker Pond with respect to the 2013 projections. In addition, we evaluate the potential impact of modified effluent phosphorus loading rates at Site 7 on downgradient phosphorus adsorption capacity.

2 Current Conditions

2.1 Monitoring Wells

Since publication of the 2013 study, infiltration beds designated as beds 14 and 15 were installed at Site 7 and began operation in early 2017. Monitoring wells have been constructed along the predicted flow path of infiltrated wastewater (**Figure 1);** the wells are monitored routinely for a suite of indicator parameters including phosphorus. Details of the monitoring wells, including the depth of screened interval and distance downgradient of the infiltration beds, are listed in **Table 1.**

Figure 1
Falmouth Main WWTF – Locations of Recharge Beds 1-15 and Monitoring Wells



Source: Falmouth WWTF

Table 1
Monitoring Wells Associated with Beds 14 & 15

Town Well ID	GHD Well ID	Well Depth (ft)	Distance from Sand Bed (ft)
MW25A	GHD-3A	97.9	1847.81
MW25B	GHD-3B	117.75	1858.59
MW21A	GHD-4A	69	12.14
MW21B	GHD-4B	97	11.64
MW22A	GHD-5A	46.16	180.68
MW22B	GHD-5B	74.5	170.98
MW23A	GHD-6A	72	225.76
MW23B	GHD-6B	98	238.69

Town Well ID	GHD Well ID	Well Depth (ft)	Distance from Sand Bed (ft)
MW20	GHD-1	85.25	130.42 (upgradient)
MW24	GHD-2	95	1437.71

Source: GHD, Drawing of Overall Site Plan – Proposed Recharge Beds 14 & 15, Town of Falmouth, MA

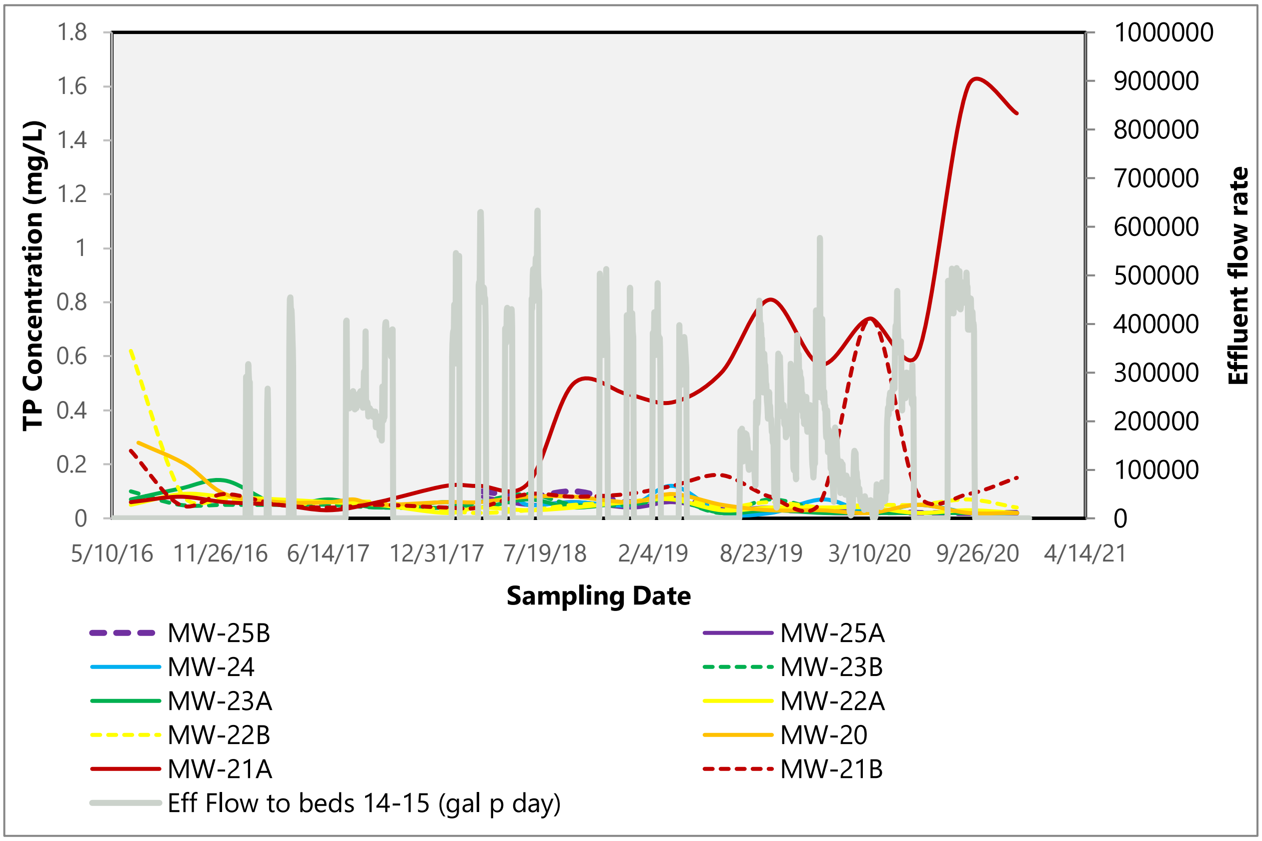
The Falmouth WWTF operates under permit conditions specified in permit 168-6 (Mass DEP, 2020). Flow to sand beds 14 and 15 are capped at 260,000 gallons per day (GPD) as an annual average, with a maximum daily limit of 470,000 GPD. Flow through sand beds 14 and 15 are monitored daily. Total phosphorus and orthophosphate are sampled quarterly. In addition, monitoring wells were sampled quarterly for total phosphorus and orthophosphate.

Results of quarterly total phosphorus testing of monitoring wells downgradient of infiltration beds 14 & 15 are displayed in **Figure 2** along with effluent application rates. As evident from the graph, the infiltration beds do not receive constant flow of treated effluent. Rather, the Falmouth WWTF sequences effluent application among its permitted infiltration beds. Testing of the monitoring wells began in mid-2016; wastewater application to infiltration beds 14 and 15 began in January 2017.

In general, groundwater phosphorus concentrations have remained consistent over the monitoring period to date. The one exception is monitoring well 21A; this well is sited 12 ft. directly downgradient of the infiltration beds. Phosphorus concentrations in this monitoring well are directly affected by infiltrating wastewater due to the flux rate and minimal contact with native soils. However, phosphorus concentrations measured in monitoring well 21B do not exhibit the same reactivity, likely because of the increased depth to the screened interval and associated increased opportunity for phosphorus attenuation within the soil profile.

Monitoring data collected to date indicate no issues of potential concern related to downgradient phosphorus migration based on operating conditions of the Falmouth WWTF. Wastewater volume and loading vary seasonally with population served.

Figure 2
TP Concentrations in Monitoring Wells Associated with Sand Beds 14 & 15



Source: Falmouth WWTF

2.2 Crocker Pond

Crocker Pond is currently monitored annually to track productivity and water quality conditions. Samples are collected monthly during the summer recreational season (July, August, and September) and submitted for laboratory analysis of total phosphorus, total inorganic nitrogen, total organic nitrogen, and chlorophyll-a. The field sampling team also measures Secchi disk transparency, an indication of water clarity. Results of trophic state indicator parameters measured between 2016 and 2020 are summarized in **Table 2**.

Table 2
Crocker Pond Water Trophic State Indicator Parameters, 2016-2020

Month-Year	pH	TP at 0.5 m (mg/L)	Chlorophyll-a (ug/L)	Secchi depth (m)
Jul-16	6.32	0.025	1.06	3.5
Aug-16	6.59	0.013	1.82	4.5

Month-Year	pH	TP at 0.5 m (mg/L)	Chlorophyll-a (ug/L)	Secchi depth (m)
Sep-16	6.5	0.013	1.14	3.6
Jul-17	6.48	0.018	1.02	4.3
Aug-17	6.52	0.015	2.27	5.15
Sep-17	6.58	0.018	1.27	6.2
Jul-18	6.82	0.021	1.27	2.4
Aug-18	6.59	0.022	1.14	4.3
Sep-18	6.52	0.016	1.86	4
Jul-19	6.39	0.013	3.16	4.09
Aug-19	6.48	0.012	3.4	4.55
Sep-19	6.38	0.022	3.35	6.1
Jul-20	6.71	0.042	1.99	4.2
Aug-20	6.95	0.017	1.96	3.92
Sep-20	6.58	0.017	2.06	4.1

Source: Falmouth WWTF

Phosphorus concentrations differ between the surface and deep layers of Crocker Pond (**Figure 3**). This pattern is typical of kettle ponds that are deep enough to develop stable thermal stratification; deeper waters remain isolated from atmospheric exchange during summer. Depletion of dissolved oxygen in the deeper waters can result in chemical changes at the sediment surface and the release of legacy phosphorus. The impact is evident in the higher phosphorus concentrations measured in Crocker Pond during August and September sampling events.

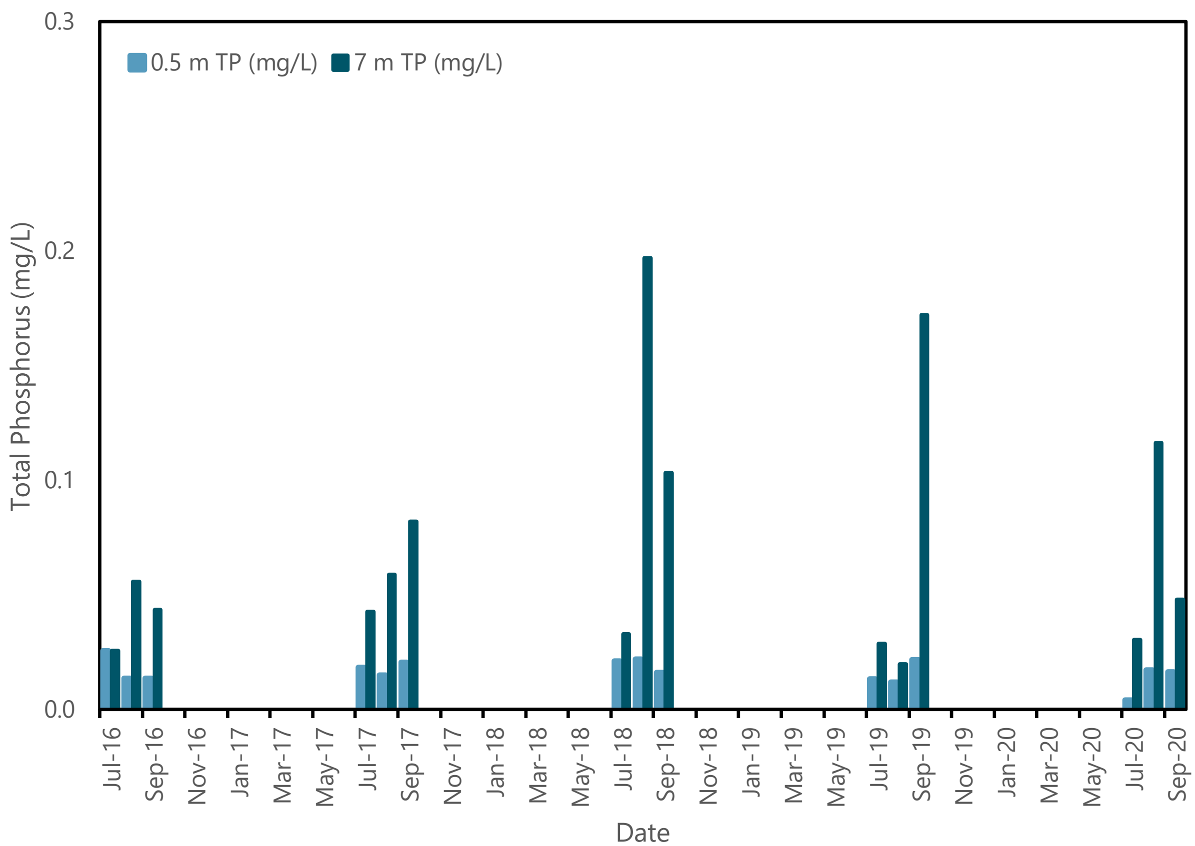
Baseline data for Crocker Pond's trophic state indicator parameters were compiled as part of the 2013 evaluation. These data were collected under the PALS program in 2001, 2004-2007 using comparable sampling and analytical protocols in place since 2016. Data collected between 2016 and 2020 indicate the interannual variability in pond water quality conditions.

Table 3
Crocker Pond Trophic State Parameter Tracking

Year	Total P, ug/L	Chlor-a, ug/L	Secchi disk transparency, m
2001	15.1	1.65	4.3
2004	12.9	2.07	4.0
2005	7.9	2.41	4.7
2006	16.7	3.22	4.7
2007	7.7	2.40	1.5
2016	13.0	1.14	3.3

2017	17.0	1.52	5.2
2018	19.6	1.42	3.6
2019	15.7	3.30	4.9
2020	25.3	2.00	4.1

Figure 3
Baseline Total Phosphorus Concentrations at Crocker Pond, 2016-2020



Source: Falmouth WWTF (sent by Amy Lowell, allcrockerpond.xlsx

3 Testing Scenarios

Downgradient phosphorus attenuation of infiltrated effluent is governed by the volume of soil to which the infiltrating treated wastewater effluent is exposed (soil prism), the mass and concentration of phosphorus present in the treated wastewater, the rate of infiltration and groundwater flux, and the adsorptive capacity of the soil prism.

3.1 Retention Capacity Calculations

An empirical model was applied to estimate phosphorus retention capacity of the soil. Model projections are primarily driven by the amount of reactive aluminum present in the soils and the downgradient prisms through which the applied effluent will migrate. GHD identified an effluent flow rate of 0.5 MGD for this empirical groundwater modeling scenario. We evaluated this scenario at different total phosphorus effluent concentrations to support a sensitivity analysis. Model input parameters and results are provided in **Table 4**.

Table 4
Model Input Parameters and Results

Input	Scenario 0.5 at 0.2 mg/L	Scenario 0.5 at 2.5 mg/L	Scenario 0.5 at 3.14 mg/L	Source or Calculation
P Loading Characteristics				
Proposed volume of infiltrated wastewater at Allen Parcel (MGD)	0.55			GHD Scenario Proposal
Proposed volume of infiltrated wastewater at Allen Parcel (L/d)	2,081,976			GHD Scenario Proposal (unit conversion)
Current effluent concentration (mg/L)	0.2	2.5	3.14	Falmouth WWTF (WWTF eff flow N-P.xlsx)
Estimated TP load at specified effluent concentration mg/L (kg/yr)	151.98	1,899.80	2,386.15	Proposed volume of infiltrated wastewater at Allen Parcel * Projected Effluent concentration * 365 d
Soil Characteristics				
Soil Porosity (g/cm^3)	1.6			Average bulk density based on soil texture data
Al content of unsaturated soils (mg/kg)	732			2013 Crocker Pond Soil Boring
Al content of saturated soils (mg/kg)	773			2013 Crocker Pond Soil Boring

Input	Scenario 0.5 at 0.2 mg/L	Scenario 0.5 at 2.5 mg/L	Scenario 0.5 at 3.14 mg/L	Source or Calculation
% of reactive Al in unsaturated soils (%)	10			2013 EcoLogic Report, Crocker Pond
% of reactive Al in saturated soils (%)	5			2013 EcoLogic Report, Crocker Pond
Molar ratio of reactive Al to P binding sites (kg P/kg Al)	0.3			2013 EcoLogic Report, Crocker Pond
Crocker Pond				
% of Plume intercepting Crocker Pond	21.9			GHD particle track analysis
Unsaturated prism (m^3)	56,878.32			GHD calculation
Saturated prism (m^3)	3,903,535.30			GHD calculation
Capacity of unsaturated zone to sequester P (years)	60.04	4.80	3.82	Bound P to Al in unsaturated soil / Estimated TP load
Capacity of saturated zone to sequester P (years)	2,175.74	174.06	138.58	Bound P to Al in saturated soil / Estimated TP load

3.2 Phosphorus Sequestration Capacity

The volume of soil interacting with the infiltrating wastewater plume (the soil prism) can be estimated using various assumptions. For this assignment, the volume of the soil prism was estimated using a particle tracking model to project the flow path of infiltrated effluent toward Crocker Pond. The particle track analysis estimates that 21.9% of infiltrated wastewater will enter Crocker Pond under the 0.55 MGD scenario.

The soil prism calculation incorporates the three dimensions (depth of vertical penetration, lateral plume width and horizontal distance to each waterbody). The soil prism was multiplied by the soil's bulk density (1.6×10^6 g/cm^3) to estimate the mass of soil within the flow path of the infiltrating wastewater plume. We estimated the phosphorus sequestration capacity using site-specific data (aluminum content), aluminum reactivity, and the mass of soil to calculate potential phosphate binding sites. The soil prism was divided into saturated and unsaturated zones to differentiate aerobic and anaerobic processes governing phosphorus sequestration. The result of this calculation is provided in **Table 3**.

The potential contributions of other reactive minerals that play a role in phosphorous sequestration (notably iron and manganese) are not included in the model calculations. Inclusion of these other minerals would increase capacity even further.

With an effluent flow rate of 0.55 MGD and a TP effluent concentration of 2.5 mg/L, it is estimated that the soil has a phosphorus attenuation capacity of nearly 180 years.

3.3 Sensitivity Analysis

There are numerous assumptions that affect the calculated phosphorus binding capacity downgradient of the Allen Parcel. Because the phosphorus concentration in wastewater effluent determines the amount of phosphorus molecules that need to be adsorbed or precipitated, a sensitivity analysis was performed under various total phosphorus effluent concentrations. To ensure that the sensitivity analysis is based on relevant environmental conditions, a total phosphorus effluent concentration of 0.2 mg/L (anticipated under tertiary treatment) was used, as well as a TP effluent concentration of 3.14 mg/L, consistent with current TP effluent concentrations from the Falmouth WWTF. Results of the sensitivity analysis at each concentration is provided in **Table 4**. Under the 0.2 mg/L and the 3.14 mg/L TP effluent concentration, the soil has a phosphorus attenuation capacity of 2,200 years and 140 years, respectively.

4 Recommendations for Monitoring

It is recommended that the Falmouth WWTF continue monitoring Crocker Pond to track trends in water quality and habitat. Consistent field and laboratory protocols will facilitate trend analysis. Annual monitoring can help document year-to-year variability and build upon the existing baseline characterization. The recommended long term monitoring program is described in **Table 5**.

Table 5
Recommended Long-Term Monitoring Program

Parameter	Rationale	Sampling Protocol
Water temperature and dissolved oxygen profile	Aquatic habitat, evidence of DO depletion	Sample at 1 m intervals at deepest point in pond in summer months (June-Sept)
Nearshore (littoral zone) habitat plant community, algal abundance, sediment types	Establish baseline, consider whether recreational access is impaired	Single survey, July
Trophic state parameters: total P, total N, chlorophyll-a, secchi disk transparency	Baseline productivity level	Two depths: surface and deep. Sample in summer months (June-September)

Parameter	Rationale	Sampling Protocol
Current recreational access points and protected lands	Document how the resource is used	Field observations and mapping
Septic systems within 300 ft. of waterbodies	Estimate potential for phosphorus contribution from septic systems	Field observations and mapping
Land use and impervious surfaces in watershed	Estimate potential for phosphorus contribution from stormwater	Field observations and mapping

5 References

EcoLogic, 2013. Potential Soil Attenuation of Phosphorus Migration from Infiltrating Treated Water Recharge at Site 7.

Mass DEP, 2020. Individual Groundwater Discharge permit. Falmouth WWTF: Permit No. 168-6.